Khalilian, A., C.E. Hood, J.H. Palmer, T.H. Garner, and G.R. Bathke. 1991. Soil compaction and crop response to wheat/soybean interseeding. Trans. ASAE 34:2299–2303.
Langdale, G.W., W.C. Mills, and A.W. Thomas. 1992. Use of conservation tillage to retard erosion effects of large storms. J. Soil Water Conserv. 47:257–260.
Large, E.C. 1954. Growth stages in cereals: Illustrations of the Feekes scale. Plant Pathol. 3:128–129.
Martin, C.K., D.K. Cassel, and E.J. Kamprath. 1979. Irrigation and tillage effects on soybean yield in a Coastal Plain soil. Agron. J. 71:592–594.
NeSmith, D.S., W.L. Hargrove, D.E. Radcliffe, E.W. Tollner, and H.H. Arioglu. 1987. Tillage and residue management effects on properties of an Ultisol and double-cropped soybean production. Agron. J. 79:570–576.

Row Spacing and Weed Management Systems for Nonirrigated Early Soybean Production System Plantings in the Midsouthern USA

Larry G. Heatherly,* C. Dennis Elmore, Richard A. Wesley, and Stan R. Spurlock

ABSTRACT

The new paradigm for soybean [*Glycine max* (L.) Merr.] production in the midsouthern USA is the Early Soybean Production System (ESPS), which involves planting early-maturing cultivars in April. Field studies were conducted for 3 yr at Stoneville, MS, on Sharkey clay (very-fine, smectitic, thermic chromic Epiaquert) with a MG IV soybean cultivar grown in 0.5-m-wide rows (NR) and a MG V cultivar grown in 1-m-wide rows (WR), both with varying weed management inputs, to determine the most profitable system for nonirrigated ESPS plantings. Weed management in NR consisted of broadcast application of herbicides. Weed management in WR included band (0.5-m-wide) application of herbicides plus two to three between-row cultivations. Total weed cover at harvest in all treatments was below 10% in the first 2 yr. In the third year, browntop millet [*Brachiaria ramosa* (L.) Stapf.] plus pitted morningglory (*Ipomoea lacunosa* L.) percentages exceeded 10% in 3 of 10 treatments in NR and in 1 of 10 treatments in WR, but these treatments were among those producing the highest yield and net return. Soybean treated for preemergence (PRE) broadleaf management, PRE broadleaf plus PRE grass management, PRE broadleaf plus postemergence (POST) grass management, and PRE and POST broadleaf plus PRE and POST grass management were among the highest yielding treatments, but only the treatment of PRE broadleaf management provided the highest net return across both NR and WR. Soybean with PRE and POST broadleaf plus PRE grass management provided the lowest net returns across both NR and WR. These results indicate that only a broadcast PRE broadleaf herbicide in NR and a PRE banded broadleaf herbicide plus POST cultivation in WR in an ESPS planting that is not irrigated will produce yield and net return that are among the highest, and weed management cost that is among the lowest of ≤$62 ha^{-1}.

The early soybean production system (necessary seedbed preparation tillage in the fall; winter–spring weeds killed with a preplant, non-selective herbicide; early-maturing cultivars planted into a stale, untilled seedbed in April; Heatherly, 1999a) vs. the Conventional Soybean Production System (CSPS: May and June planting of later-maturing cultivars) offers an alternative for soybean production in the midsouthern USA (Boquet, 1998; Bowers, 1995; Heatherly and Spurlock, 1999). Use of the ESPS will preclude preplant tillage on soils such as shrink-swell clays that are usually spongy because of near-saturation in early spring, the time of intended planting (Pettry and Switzer, 1996). Thus, a stale seedbed system of planting (Heatherly, 1999b) should be used with this early-planted soybean production system.

The ESPS is suited for the use of narrow-row (≤0.5 m) culture to accomodate the narrow growth habit of indeterminate MG IV cultivars (Heatherly and Bowers, 1998). However, wide-row soybean production systems are still used because they match the row spacing requirements of other row crops used in a producer's rotation. Narrow-row systems preclude POST cultivation that normally has been used in wide rows (≥0.75 m) of the CSPS (Buhler et al., 1997; Hooker et al., 1997; Newsom and Shaw, 1996; Swanton et al., 1998). Thus, determination of economically feasible weed management systems using broadcast-applied PRE and POST herbicides without POST cultivation in narrow rows and band-applied PRE and POST herbicides with POST cultivation in wide rows in the ESPS is necessary. These management systems must provide options for economical management of both summer broadleafs and grasses to attain maximum economic yield.

Soybean, especially that not irrigated, provides relatively low gross return with a small profit margin in the midsouthern USA (Heatherly et al., 1994; Heatherly and Spurlock, 1999; Williams, 1999). The small profit margin from soybean grown without irrigation dictates that all costs associated with production, including pest management costs, must be minimized. In previous research at Stoneville where drought was common during the reproductive period of soybean, level of weed management in a nonirrigated CSPS was of little consequence in regard to soybean yield when the weeds present were not highly competitive species (Heatherly et al., 1994). However, it is impractical to plan a weed management program for soybean based on the assumption that drought stress will result in low and unprofitable yield since weed management expenditures are made early in the growing season.

L.G. Heatherly, USDA-ARS, Crop Genetics and Prod. Res. Unit, P.O. Box 343, Stoneville, MS 38776; C.D. Elmore and R.A. Wesley, USDA-ARS Application and Production Technology Research Unit, P.O. Box 36, Stoneville, MS 38776; S.R. Spurlock, Economist, Dep. of Agric. Econ., P. O. Box 9755, Mississippi State, MS 39762. Received 21 April 2000. *Corresponding author (lheatherly@ars.usda.gov).

Published in Crop Sci. 41:784–791 (2001).

Abbreviations: CSPS, conventional soybean production system; DAP, days after planting; ESPS, early soybean production system; MG, maturity group; NR, narrow-row system; NETRET, net return; PFA, preplant foliar-applied; POST, postemergence; PRE, preemergence; WR, wide-row system; WTRT, weed management treatment.

Inputs used for weed management in soybean represent a significant cost (Buhler et al., 1997; Heatherly et al., 1994; Johnson et al., 1997), and must be managed early (PRE) or on an as-needed basis (POST). In narrow-row soybean plantings made in a stale seedbed, effective weed management systems will almost exclusively involve herbicides (Johnson et al., 1997, 1998; Oliver et al., 1993). Use of combinations of PRE and POST herbicides with POST cultivation is commonplace in wide-row production systems in the midsouthern USA (Askew et al., 1998; Heatherly et al., 1993, 1994; Hydrick and Shaw, 1995; Oliver et al., 1993; Poston et al., 1992).

Many weed management systems will provide a similar level of weed control, but cost differences can be large (Buhler et al., 1997; Heatherly et al., 1993, 1994). These cost differences, coupled with differences in yield among weed management systems, can mean significant differences in net return among systems of weed management (Buhler et al., 1997; Heatherly et al., 1993, 1994; Johnson et al., 1997). The best weed management systems for ESPS plantings must be determined to maximize profits from this higher-yield-potential production system.

Plantings using the ESPS are being made in fields previously cropped by the CSPS where weed control was excellent. Row spacing–cultivar–weed management systems for continuous ESPS plantings in these situations have not been evaluated. The objective of this study was to determine the effect of PRE and POST weed management on weed cover, seed yield, and net return for continuous nonirrigated plantings of a MG IV cultivar grown in 0.5-m-wide rows and a MG V cultivar grown in 1-m-wide rows.

MATERIALS AND METHODS

The study was conducted in the summers of 1994, 1995, and 1996 at the Delta Research and Extension Center (DREC), Stoneville, MS, (33°26′N). The experimental site had been cropped with soybean in a CSPS with well-controlled weed populations for the past 15 yr. Soil series was Sharkey clay, which is characterized by less than 10 g kg^{-1} organic matter, poor internal drainage, high fertility level, less than 0.3% slope, low bulk density, and textural uniformity with depth. Weather data were collected about 0.8 km from the experimental site by NOAA, Mid-south Agric. Weather Service Center in 1994 and 1995, and by DREC personnel in 1996. Experimental design was a randomized complete block with a split-plot arrangement of treatments in four replicates. System (NR = MG IV soybean cultivar grown in 0.5-m-wide rows and WR = a MG V cultivar grown in 1-m-wide rows) was assigned to the main plot, and weed management treatment (WTRT) was assigned to the sub-plot. The study was not repeated since the objective was to determine effect of system and WTRT where the ESPS was used continuously over a period of years.

Several assumptions were made in the selection of the two systems used in this study. An indeterminate MG IV cultivar with its non-branching canopy structure was assumed to be suited to NR, while a determinate MG V cultivar with its branching, bushy canopy structure was assumed to be suited to WR. A wide-row system will necessarily have a wider open space to fill, and MG V cultivars that branch profusely and form a bushy canopy should fill the between-row area. On the other hand, MG IV cultivars do not branch significantly above the lower nodes and have a narrow, upright profile. Thus, they are not as likely to close the open area in wide rows. Therefore, the selection of the two systems was based on the expectation of each cultivar's particular canopy structure fitting its assigned row width.

Plots were 4 m wide (eight rows in NR and four rows in WR) and 30.5 m long. Seeding rate was 16 seed m^{-1} of 0.5-m-wide rows and 32 seed m^{-1} of 1.0-m-wide rows. Treatments were randomly assigned to plots in 1994, and remained in the same location thereafter. 'RA 452' (1994 and 1995) and 'DK 4875' (1996) (MG IV indeterminates) were planted in NR and 'DP 3589' (MG V determinate) was planted in WR on 20 April 1994, 17 April 1995, and 10 April 1996. All plantings were made in a stale seedbed where glyphosate at 840 g ai ha^{-1} in 94 L water ha^{-1} was applied preplant to kill emerged weeds at planting.

Weed management treatments each year were: WTRT 1, PRE broadleaf management; WTRT 2, POST broadleaf management; WTRT 3, PRE broadleaf plus POST broadleaf management; WTRT 4, PRE broadleaf plus PRE grass management; WTRT 5, PRE broadleaf plus POST grass management; WTRT 6, PRE grass plus POST broadleaf management; WTRT 7, POST broadleaf plus POST grass management; WTRT 8, PRE broadleaf plus POST broadleaf plus PRE grass management; WTRT 9, PRE broadleaf plus POST broadleaf plus POST grass management; and WTRT 10, PRE broadleaf plus POST broadleaf plus PRE grass plus POST grass management. The study rationale and selection of the above WTRTs assumed the following.

1. Uncontrolled weeds will reduce yield of soybean; thus, there was no comparison of the selected WTRTs to a weedy check.
2. The inclusion of economic analyses in this study dictated that all WTRTs be practical and realistic, so there was no intent to determine how WTRT related to an economically unattainable or unfeasible weed-free check treatment.
3. The selected WTRTs assumed that broadleaf weeds but not necessarily grass weeds in a dryland environment must be controlled.
4. Cultivation in WR was assumed to be a POST weed control measure, and could be used in lieu of POST herbicides in a treatment with a POST component.
5. The intent in selecting the WTRTs was to have weed management options that differ in cost, and broadcasting of herbicides in NR vs. the banding of herbicides along with supplemental POST cultivation in WR is one way of doing this. Another way is to use PRE (based on expected weed infestations) vs. POST (based on actual weed infestations) herbicides in various combinations.
6. Broadcasting herbicides in NR was presumed to create a different environment than the banding of herbicides plus cultivation in WR.

Selection of PRE herbicides was based on expected weed populations, whereas selection of POST herbicides was based on expert opinion resulting from assessment of the presence and size of particular weed species in plots of each WTRT within each system. Herbicides applied to each WTRT within each system are shown in Table 1. Herbicides were broadcast-applied to NR and applied to a 0.5-m-wide band centered over each row in WR. Between-row areas in WR were cultivated three times in 1994 and 1995 and twice in 1996. Rainfall of 20 mm or greater was received 9, 2, and 3 d following PRE herbicide applications in 1994, 1995, and 1996, respectively.

Herbicides were applied with a canopied sprayer (Ginn et al., 1998a) for over-the-top applications (to prevent drift to adjacent plots of different treatments) or a directed sprayer

Table 1. Weed management treatment (WTRT) and herbicides applied to nonirrigated MG IV soybean grown in narrow rows (NR) and MG V soybean grown in wide rows (WR) at Stoneville, MS, 1994–1996.

WTRT†	Herbicides and years applied‡
1 PRE broadleaf	Metribuzin + chlorimuron (all years, NR & WR).
2 POST broadleaf	Bentazon + acifluorfen (1994 NR & WR, 1995 NR, 1996 NR); fomesafen (1994 NR & WR, 1995 NR & WR); 2,4-DB + linuron (1996 NR & WR).
3 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
POST broadleaf	Bentazon + acifluorfen (1995 NR); fomesafen (1994 NR & WR, 1995 NR); 2,4-DB + linuron (1995 WR, 1996 NR & WR).
4 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
PRE grass	Metolachlor (all years, NR & WR).
5 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
POST grass	Sethoxydim (1994 NR & WR, none in 1995, 1996).
6 PRE grass plus	Metolachlor (all years, NR & WR).
POST broadleaf	Bentazon + acifluorfen (1994 NR & WR, 1995 NR, 1996 NR); fomesafen (1994 NR & WR, 1995 NR & WR); 2,4-DB + linuron (1996 NR & WR).
7 POST broadleaf plus	Bentazon + acifluorfen (1994 NR & WR, 1995 NR, 1996 NR); fomesafen (1994 NR & WR, 1995 NR & WR); 2,4-DB + linuron (1996 NR & WR).
POST grass	Sethoxydim (1994 NR & WR; none in 1995, 1996).
8 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
POST broadleaf plus	Bentazon + acifluorfen (1995 NR); fomesafen (1994 NR & WR, 1995 NR); 2,4-DB + linuron (1995 WR, 1996 NR & WR).
PRE grass	Metolachlor (all years, NR & WR).
9 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
POST broadleaf plus	Bentazon + acifluorfen (1995 NR); fomesafen (1994 NR & WR, 1995 NR); 2,4-DB + linuron (1995 WR, 1996 NR & WR).
POST grass	Sethoxydim (1994 NR & WR; none in 1995, 1996).
10 PRE broadleaf plus	Metribuzin + chlorimuron (all years, NR & WR).
POST broadleaf plus	Bentazon + acifluorfen (1995 NR); fomesafen (1994 NR & WR, 1995 NR); 2,4-DB + linuron (1995 WR, 1996 NR & WR).
PRE grass plus	Metolachlor (all years, NR & WR).
POST grass	Sethoxydim (1994 NR & WR; none in 1995, 1996).

† All plantings received PFA glyphosate. PRE = applied preemergence; POST = applied postemergence.
‡ Premix and tankmix combinations indicated by +.

(Ginn et al., 1998b) for applications underneath the developing soybean canopy. All PRE herbicides and POST broadleaf herbicides were applied in 187 L of water ha^{-1}, and POST grass herbicides were applied in 94 L of water ha^{-1}. Surfactants were used in accordance with herbicide manufacturer's recommendations. POST herbicides were selected and applied to control specific weed problems that were determined on a treatment-by-treatment basis during the growing season. The intention was to minimize weed competition as a factor within the constraints of each treatment in the experiment. Weed management costs were calculated for each treatment and included herbicides, surfactants, and their application in both NR and WR systems, plus POST cultivation in the WR system.

Total weed cover by species was determined prior to harvest each year, but after soybean leaf senescence had begun (Elmore and Heatherly, 1988) to measure the season-long effect of the weed management treatments. Visual estimates of weed cover in 10% increments from 0 to 100% were made in five randomly chosen 0.5-m^2 sample areas in each plot to estimate cover for each weed species. If a species was merely present in any of the samples of an individual plot, then its relative abundance was assigned the lowest possible score (0–10%), with an average of 5% cover in that sample. This is similar to the process used by Yelverton and Coble (1991) to measure weed resurgence at the end of the growing season following early-season application of weed management treatments intended to give 100% control.

Estimates of costs and returns were developed for each annual cycle of each experimental unit by the Mississippi State Budget Generator (referred to as MSBG—Spurlock and Laughlin, 1992). Total specified expenses were calculated from retail cost for each treatment input in each year of the study, and included all direct and fixed costs, but excluded costs for land, management, and general farm overhead which were assumed to be the same for all treatment combinations. Direct expenses included costs for herbicides, seed, labor, fuel, machinery repair and maintenance, hauling harvested seed, and interest on operating capital. Fixed expenses were ownership costs for tractors, self-propelled harvesters, implements, and sprayers. Costs of variable inputs and machinery were based on prices paid by Mississippi farmers each year; i.e., machinery costs varied with year. Annual depreciation of all machinery was calculated by the straight-line method with zero salvage value. Annual interest charges were based on one-half of the original investment times an appropriate interest rate for each year of the study. Insurance was estimated at 1% of the original investment.

Income from each experimental unit was calculated from the market-year average price of \$0.21/kg in 1994, \$0.24/kg in 1995, and \$0.26/kg in 1996 for Mississippi. Yearly prices vs. an average long-term price were used to reflect the effect of market forces on income for each individual year. Net return above total specified expenses was determined for each experimental unit each year.

Soybean plant height at maturity was recorded for each sub-plot just prior to harvest. A field combine modified for small plots was used to harvest the four center rows of NR plots and the two center rows of WR plots. Soybean seed were harvested on 14 Sept. (RA 452) and 22 Sept. (DP 3589) 1994, 7 Sept. (RA 452) and 20 Sept. (DP 3589) 1995, and 9 Sept. (DK 4875) and 24 Sept. (DP 3589) 1996. Harvested seed were weighed and adjusted to 130 g moisture kg^{-1} of seed. Analysis of variance [PROC MIXED (SAS Institute, 1996)] was used to evaluate the significance of effects on weed cover, seed yield, and net returns. Analyses across years treated year as a fixed effect to determine interactions involving year. Analyses for individual years treated system (NR and WR) and WTRT as fixed effects. Mean separation was achieved with an LSD at $P \leq 0.05$.

RESULTS AND DISCUSSION

Weather and Soybean Development

The MG IV cultivar started blooming on 7 June 1994, 12 June 1995, and 20 May 1996. The MG V cultivar started blooming on 15 June 1994, 19 June 1995, and 7 June 1996. The seedfill period for the MG IV cultivar occurred from 21 July to 19 Aug. 1994, from 24 July to

Table 2. Average daily minimum and maximum air temperature, monthly rainfall, and pan evaporation at Stoneville, MS, 1994–1996, and 1964–1993 weather normals (Boykin et al., 1995).

Month	Weather variable	1994	1995	1996	30-yr normal
May	Minimum air temperature (°C)	16.1	18.3	19.4	16.6
	Maximum air temperature (°C)	27.8	31.1	31.1	27.9
	Rainfall (mm)	130	79	62	127
	Pan evaporation (mm)	194	202	269	196
	Rainfall - pan evaporation (mm)	−64	−123	−207	−69
June	Minimum air temperature	22.8	20.0	21.1	20.7
	Maximum air temperature	33.3	31.7	31.7	31.9
	Rainfall	51	102	133	94
	Pan evaporation	198	224	178	216
	Rainfall - pan evaporation	−147	−122	−45	−122
July	Minimum air temperature	22.2	22.8	22.8	22.2
	Maximum air temperature	32.2	32.8	32.8	33.0
	Rainfall	295	148	84	94
	Pan evaporation	165	213	201	208
	Rainfall - pan evaporation	130	−67	−117	−114
August	Minimum air temperature	19.4	23.3	20.6	21.0
	Maximum air temperature	32.8	35.0	31.7	32.3
	Rainfall	13	36	110	58
	Pan evaporation	175	218	162	185
	Rainfall - pan evaporation	−162	−182	−52	−127

24 Aug. 1995, and from 24 June to 2 Aug. 1996. The seedfill period for the MG V cultivar occurred from 29 July to 2 Sept. 1994, from 28 July to 5 Sept. 1995, and from 19 July to 27 Aug. 1996. Maturity of the cultivars was reached on 2 Sept. (MG IV) and 14 Sept. (MG V) 1994, 15 Sept. (MG IV) and 22 Sept. (MG V) 1995, and 23 Aug. (MG IV) and 12 Sept. (MG V) 1996.

Average minimum and maximum air temperatures, and rainfall and pan evaporation for May, June, July, and August of each year are shown in Table 2. The major difference in the weather of the 3 yr occurred in July and August. July rainfall was greatest in 1994 (295 mm) when it was spread throughout the month (last rain of 66 mm on 26 July), and exceeded pan evaporation by 130 mm. August rainfall in 1994 was negligible. The high July rainfall evidently provided moisture for most of the seedfill period of both cultivars (21 July–19 Aug. for MG IV cultivar and 29 July–2 Sept. for the MG V cultivar). In 1995, all but 30 mm of the 148 mm of July rain occurred before 6 July. Only 66 mm of rain was received during the remainder of July and all of August, and this low amount provided inadequate moisture during the seedfill period of both cultivars. In 1996, over one-half of the low July rainfall of 84 mm occurred on 31 July, and August rainfall totaled 110 mm. These rainfall amounts and times favored the seedfill period of the MG V cultivar (19 July–27 Aug.) vs. that of the MG IV cultivar (24 June–2 Aug.).

Soybean plant height at maturity in the NR system (MG IV cultivar) was 90, 88, and 57 cm in 1994, 1995, and 1996, respectively. For the WR system (MG V cultivar), plant height at maturity was 88, 70, and 64 cm in 1994, 1995, and 1996, respectively.

Weed Cover and Weed Management Costs

In 1994, all POST herbicides were applied between 6 May (16 DAP) and 7 June (48 DAP). In 1995, all POST herbicides were applied between 31 May (44 DAP) and 19 June (64 DAP). In 1996, all POST herbicides were applied between 20 May (40 DAP) and 5 June (56 DAP). POST grass control was not needed in 1995 and 1996 (no grasses present), and this component was not applied to treatments designated to get a POST grass herbicide. All weed management treatments controlled target species at time of application. Thus, weed cover at harvest represented those weeds that appeared after weed management measures had been completed each year.

All weed cover values in 1994 and 1995 were below 10% in both NR and WR (Table 3). In 1994, average weed cover in the NR system was 6%, and this significantly exceeded the 2% average cover in the WR system (Table 3). Pitted morningglory was the dominant species. System × WTRT interacted in 1995 and 1996 to significantly affect weed cover. In both years, weed cover in the PRE broadleaf management treatment (WTRT 1) of the NR system (8% in 1995 and 21% in 1996) exceeded that in all other WTRTs of that system, as well as that in all WTRTs of WR. This sometimes greater weed cover in the NR system of this study is different from the relationship between NR and WR weed populations in the northern USA (Mickelson and Renner, 1997) and Ontario, Canada, (Swanton et al., 1998). This is attributed to the early maturity of the MG IV cultivar in the NR system of this study, which resulted in late-season weed infestations during soybean maturity and canopy opening in August. In the WR system, all weed cover values were ≤2% in 1995, and ranged from 5 to 11% in 1996, with no significant differences among WTRTs. The dominant weed species in 1995 again was pitted morningglory, while in 1996, both browntop millet and pitted morningglory were dominant in both NR and WR. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] was the only other annual grass that appeared prominently in any treatment. The occurrence of annual grass at soybean maturity in 1996 was likely due to 110 mm of rain that occurred in August when soybean was maturing and the soybean canopy was opening.

In all years, weed management costs for all WTRTs in the NR system exceeded those for the same WTRTs in the WR system. Thus, banding of herbicides plus

Table 3. Total weed cover, major weed species present, and cover of major species as affected by weed management (WTRT) in MG IV soybean grown in narrow rows (NR) and MG V soybean grown in wide rows (WR) near Stoneville, MS, 1994–1996.

WTRT†	Cover‡ NR	Cover‡ WR	Major weed species and percentage cover NR	Major weed species and percentage cover WR
	%			
		1994		
1 PRE broadleaf	8	1	Pitted morningglory (PMG), 7	Several < 1
2 POST broadleaf	6	2	PMG, 4	Several < 1
3 PRE + POST broadleaf	5	3	PMG, 5	Several < 1
4 PRE broadleaf + PRE grass	4	4	PMG, 3	PMG, 3
5 PRE broadleaf + POST grass	7	3	PMG, 4	PMG, 2
6 POST broadleaf + PRE grass	7	2	PMG, 6	Several < 1
7 POST broadleaf + POST grass	7	2	PMG, 5	Several < 1
8 PRE + POST broadleaf/PRE grass	6	1	PMG, 5	Several < 1
9 PRE + POST broadleaf/POST grass	4	3	PMG, 3	Several < 1
10 PRE + POST broadleaf and grass	8	3	PMG, 8	PMG, 2
Avg.	6a	2b		
		1995		
1 PRE broadleaf	8a	1c	PMG, 6	Several < 1
2 POST broadleaf	4bc	1c	PMG, 3	Several < 1
3 PRE + POST broadleaf	2c	1c	Several < 1	Several < 1
4 PRE broadleaf + PRE grass	6b	2c	PMG, 4	Several < 1
5 PRE broadleaf + POST grass	4bc	1c	PMG, 4	Several < 1
6 POST broadleaf + PRE grass	2c	1c	PMG, 2	Several < 1
7 POST broadleaf + POST grass	4bc	1c	Several < 1	Several < 1
8 PRE + POST broadleaf/PRE grass	1c	0c	PMG, 1	
9 PRE + POST broadleaf/POST grass	1c	2c	Several < 1	Several < 1
10 PRE + POST broadleaf and grass	2c	1c	PMG, 2	Several < 1
$LSD_{0.05}$	3			
		1996		
1 PRE broadleaf	21a	6b	Browntop millet (BTM), 10; PMG, 9.	BTM, 3; PMG, 2
2 POST broadleaf	12b	7b	PMG, 6; barnyardgrass, 3; BTM, 2	BTM, 2; PMG, 2
3 PRE + POST broadleaf	7b	11b	PMG, 4; BTM, 3	BTM, 5; PMG, 2
4 PRE broadleaf + PRE grass	9b	5b	PMG, 6; BTM, 2	BTM, 2; PMG, 1
5 PRE broadleaf + POST grass	11b	8b	PMG, 5; BTM, 4	BTM, 5; PMG, 2
6 POST broadleaf + PRE grass	7b	5b	PMG, 5; BTM, 2	BTM, 3; PMG, 1
7 POST broadleaf + POST grass	8b	5b	PMG, 5; BTM, 3	BTM, 3; PMG, 2
8 PRE + POST broadleaf/PRE grass	6b	9b	PMG, 4; BTM, 2	BTM, 6; PMG, 2
9 PRE + POST broadleaf/POST grass	7b	8b	PMG, 4; BTM, 2	BTM, 5; PMG, 1
10 PRE + POST broadleaf and grass	7b	8b	PMG, 4; BTM, 2	BTM, 4; PMG, 3
$LSD_{0.05}$	7			

† See Table 2 for herbicides applied.
‡ Values within years followed by the same letter are not significantly different at $P \leq 0.05$ according to LSD. Only System (NR and WR) effect significant in 1994; System × WTRT interaction significant in 1995 and 1996.

cultivation in the WR system was cheaper than broadcasting of herbicides in the NR system. Other studies have also found that band application of herbicides plus cultivation compared to broadcast application of herbicides will result in reduced weed management costs (Krausz et al., 1995; Poston et al., 1992). The differences in weed management costs between NR and WR in this study were smallest in the PRE broadleaf management treatment (WTRT 1).

Yield and Economics

Analysis across years indicated that yield and net return were significantly affected by year × system, year × WTRT, and/or year × system × WTRT interactions. Therefore, yield and net return data are presented by years.

In 1994, system, WTRT, and the system × WTRT interaction significantly affected yield and net return. Yield from the NR system was greater in all WTRTs except the PRE broadleaf management (WTRT 1), PRE grass plus POST broadleaf management (WTRT 6), and PRE plus POST broadleaf plus PRE grass management (WTRT 8) treatments (Table 4). The lack of a difference between NR and WR in the PRE broadleaf management treatment (WTRT 1) resulted from the relatively high yield in WR, while the lack of a difference between NR and WR in the POST broadleaf plus PRE grass management (WTRT 6) and PRE plus POST broadleaf plus PRE grass management (WTRT 8) treatments resulted from relatively low yield in NR. Within WR, yields from the PRE broadleaf management (WTRT 1) and PRE grass plus POST broadleaf management (WTRT 6) treatments exceeded that from the POST broadleaf plus POST grass management (WTRT 7). In NR, yields from the PRE broadleaf plus PRE grass management (WTRT 4), PRE broadleaf plus POST grass management (WTRT 5), PRE plus POST broadleaf plus POST grass management (WTRT 9), and PRE plus POST broadleaf and PRE plus POST grass management (WTRT 10) treatments exceeded those from the POST broadleaf plus PRE grass (WTRT 6) and PRE plus POST broadleaf plus PRE grass management (WTRT 8) treatments. In the NR system, highest net returns were attained from PRE broadleaf management (WTRT 1), POST broadleaf management (WTRT 2), PRE broadleaf plus PRE grass management (WTRT 4), and PRE broadleaf plus POST grass management (WTRT 5) treatments (Table 5). These treatments consisted of only PRE or POST broadleaf management, or

Table 4. Average seed yield for MG IV soybean grown in narrow rows (NR) and MG V soybean grown in wide rows (WR) under varying weed management (WTRT) in 1994, 1995, and 1996 at Stoneville, MS.

	1994			1995			1996		
WTRT†	NR	WR	Av.	NR	WR	Av.	NR	WR	Av.
					kg ha^{-1}				
1 PRE broadleaf	2505	2415	2460	2060	1905	1985	1580	2515	2045
2 POST broadleaf	2510	2280	2395	1925	1875	1900	1420	2295	1855
3 PRE broadleaf + POST broadleaf	2505	2310	2405	1995	1855	1925	1425	2320	1870
4 PRE broadleaf + PRE grass	2590	2290	2440	2015	1895	1955	1635	2255	1945
5 PRE broadleaf + POST grass	2625	2310	2465	2005	1895	1950	1565	2485	2025
6 PRE grass + POST broadleaf	2355	2385	2370	1860	2010	1935	1310	2415	1865
7 POST broadleaf + POST grass	2530	2160	2345	1995	1830	1910	1520	2235	1880
8 PRE + POST broadleaf/PRE grass	2385	2340	2365	1930	1860	1895	1565	2315	1940
9 PRE + POST broadleaf/POST grass	2645	2255	2450	1935	1905	1920	1450	2555	2000
10 PRE + POST broadleaf and grass	2705	2225	2465	2080	1810	1945	1675	2210	1945
Av.	2535	2295		1980	1885		1515	2360	
Between System LSD	95			NS			195		
Among WTRT LSD	145			NS			NS		
System within WTRT LSD	210			NS			NS		
WTRT within system LSD	205			NS			NS		

† See Table 2 for herbicides applied.

PRE broadleaf and either PRE or POST grass management, and were the cheapest. Within the WR system, PRE broadleaf management plus POST cultivation (WTRT 1) resulted in greater profit.

In 1995, yield was not significantly affected by either system, WTRT, or their interaction (Table 4). Yields ranged from 1810 to 2080 kg ha^{-1}. On the other hand, net return was significantly affected by system, WTRT, and their interaction (Table 5). Net return from WR was greater than that from NR when PRE grass plus POST broadleaf management (WTRT 6), PRE broadleaf plus POST broadleaf plus PRE grass management (WTRT 8), and PRE broadleaf plus POST broadleaf plus POST grass management (WTRT 9) treatments were used because of greater weed management costs in NR. Differences in net returns between NR and WR were not significant when all other WTRTs were used. Within NR, highest net returns were obtained from PRE broadleaf management (WTRT 1, \$196 ha^{-1}) and PRE broadleaf plus POST grass management (WTRT 5, \$183 ha^{-1}). With WR, net returns from WTRTs 1, 2, 5, 6, and 7 were similar and in the highest ranking group. These were also the WTRTs with the lowest weed management costs.

In 1996, the 2360 kg ha^{-1} average yield from WR exceeded the 1515 kg ha^{-1} average yield from NR (Table 4). This difference was attributed to the aforementioned 1996 rainfall pattern that favored the MG V cultivar in WR. The large yield difference between WR and NR resulted in higher average net return from WR (\$366 ha^{-1} vs. \$118 ha^{-1}) (Table 5). Average yield was not significantly affected by WTRT, but average net return was. Highest net returns were \$297 ha^{-1} (WTRT 1) and \$292 ha^{-1} (WTRT 5), and these WTRTs also had the lowest weed management costs.

In both NR and WR, use of only PRE broadleaf management or only POST broadleaf management resulted in similar yields all 3 yr (Table 4). However, greater cost was associated with using only POST broadleaf management in NR, and this resulted in greater net return from the PRE broadleaf management in 1 yr, and a trend toward greater net return from this treatment in the other 2 yr in NR (Table 5). In WR, there was no clearcut trend in net returns that favored either treatment. As mentioned earlier, band application of all herbicides in WR vs. broadcast application in NR resulted in lower weed management costs for WR in all treatments all years. This contributed to the different pattern in net return differences between the two systems. Swanton et al. (1998) determined that glyphosate followed by a PRE application of a residual herbicide was the most "risk-efficient" weed management system in both NR and WR systems.

In both NR and WR, the addition of either PRE or POST grass herbicides to either PRE of POST broadleaf herbicides (WTRT 4 and WTRT 5 vs. WTRT 1, or WTRT 6 and WTRT 7 vs. WTRT 2) did not improve yield (Table 4) or net return (Table 5). In fact, the additional cost of grass herbicides with no concommitant increase in yield sometimes resulted in lower net returns (Table 5). Thus, use of grass herbicides in either NR or WR systems was not necessary in these nonirrigated ESPS plantings. This is counter to the results of Johnson et al. (1997), who found that both grass and broadleaf weed management was necessary to attain full yield potential in May and June plantings in Missouri.

In NR, soybean with PRE and POST broadleaf plus PRE grass management (WTRT 8) had yield similar to that from the PRE and POST broadleaf management only treatment (WTRT 3), but net return was usually lower. Soybean yield using PRE grass plus POST broadleaf management (WTRT 6) was similar to that from using only POST broadleaf management (WTRT 2), but net return was lower. The large amount of money spent for weed management in WTRT 6 was spent on unnecessary herbicides, since yield from this treatment was low.

In NR, several combinations of PRE and POST broadleaf and grass herbicides produced similar soybean yields (Table 4), but a large difference in the costs of these combinations occurred (Table 5). For example, the PRE broadleaf plus POST grass management treatment (WTRT 5) averaged 2065 kg ha^{-1} across the 3 yr with weed management costs of \$96, \$59, and \$59 ha^{-1},

Table 5. Weed management costs and average net returns (NETRET) for MG IV soybean grown in narrow rows (NR) and MG V soybean grown in wide rows (WR) under varying weed management (WTRT) in 1994, 1995, and 1996 at Stoneville, MS.

WTRT†	Weed control costs‡									NETRET								
	1994			1995			1996			1994			1995			1996		
	NR	WR	Av.	NR	WR	Av.	NR	WR	Av.	NR	WR	Av.	NR	WR	Av.	NR	WR	Av.
	$ ha^{-1}																	
1 PRE broadleaf	62	59	60	59	54	56	59	50	54	229	210	220	196	165	181	174	420	297
2 POST broadleaf	82	72	77	79	44	62	79	39	59	209	168	189	143	178	160	113	375	244
3 PRE broadleaf + POST broadleaf	104	83	93	138	74	106	96	71	84	184	163	173	106	133	119	94	348	221
4 PRE broadleaf + PRE grass	99	77	88	96	73	84	99	72	86	207	167	187	147	144	145	146	330	238
5 PRE broadleaf + POST grass	96	80	88	59	54	56	59	50	54	215	166	190	183	162	173	170	413	292
6 POST broadleaf + PRE grass	124	98	111	121	67	94	119	61	90	130	161	146	84	186	135	42	383	212
7 POST broadleaf + POST grass	116	93	104	79	44	62	79	39	59	175	121	148	159	158	158	139	360	250
8 PRE + POST broadleaf/PRE grass	138	102	120	175	92	134	138	93	116	122	150	136	43	115	79	88	323	205
9 PRE + POST broadleaf/POST grass	138	104	121	138	74	106	96	71	84	174	128	151	83	144	113	100	408	254
10 PRE + POST broadleaf and grass	175	123	149	175	92	134	138	93	116	147	103	125	78	104	91	116	296	206
Av.	113	89		112	67		96	64		179	154		122	149		118	366	
Between system LSD											19			30			50	
Among WTRT LSD											29			27			55	
System within WTRT LSD											42			41			NS	
WTRT within system LSD											41			38			NS	

† See Table 2 for herbicides applied.
‡ Includes herbicides, adjuvants, and application for NR and WR. Includes POST cultivation costs of \$25.05 in 1994, \$22.46 in 1995, and \$17.99 ha^{-1} in 1996 for WR. Does not include preplant non-selective herbicide that was applied to all treatments.

respectively. On the other hand, WTRT 10, the most expensive weed management treatment at \$175, \$175, and \$138 ha^{-1} for 1994, 1995, and 1996, respectively, averaged only 2155 kg ha^{-1} across the 3 yr. Evidently, the money spent for weed management in WTRT 10, as well as others, was unnecessarily high, since yields produced from these treatments were not significantly higher than yields from other treatments with lower cost and resulted in net returns that usually were lower.

In WR, yield differences among WTRTs were small and usually not significant (Table 4). However, significant differences in net returns among WTRTs within WR existed (Table 5). In all 3 yr, the five WTRTs with the least weed management costs were also the five highest ranking treatments in yield. Generally, the less money spent on weed management in WR, the greater the net returns. Cultivation used in conjunction with band application of herbicides in WR resulted in reduced production costs and increased net returns. This agrees with results from earlier studies conducted on early-May plantings at this location (Heatherly et al., 1993) and on June plantings in South Carolina (Poston et al. 1992). We did not experience any of the problems with interrow cultivation of clay soil that are mentioned by Swanton et al. (1998).

The use of net return to assess the weed management combinations resulted in a different conclusion than if yield alone was used. Use of any one of the 10 weed management combinations in this short-term study delivered similar weed management (Table 3) and yields (Table 4), but net returns (Table 5) were often different among WTRTs. In essence, using only PRE broadleaf management with either NR or WR in early-planted soybean in this dryland environment was sufficient to obtain the highest net return all 3 yr. This was true even though late-season weed infestations occurred in WTRT 1 in NR in 1996 (Table 3). Conversely, the use of only POST broadleaf management either alone (WTRT 2) or in combination with PRE or POST grass herbicides (WTRTs 6 and 7) resulted in lowered net returns because of higher weed control costs in NR, while the use of only POST broadleaf management (WTRT 2) in WR resulted in net returns that were always similar to those from WTRT 1. In this dryland environment where natural weed populations and yield potential were low, weed control expenditures of ≤\$62 ha^{-1} in both NR and WR were sufficient to achieve maximum net returns. The results from this short-term study indicate that neither weed management costs nor soybean yield can be used separately to determine the most economical system of weed management in nonirrigated ESPS plantings.

These results offer no clearcut reason to choose NR over WR or vice versa in a nonirrigated ESPS, which is counter to results obtained in more northern latitudes (Mickelson and Renner, 1997; Swanton et al., 1998). As stated earlier, weed management in NR was more expensive than in WR with no commensurate increase in weed control. Yields from most WTRTs used in NR were greater in 1994, while average yield from WR was greater in 1996. The difference in yield between the two was not significant in 1995. In 1994, 4 of the 10 WTRTs in NR resulted in greater net returns than the same treatments in WR, while in 1995, 3 of the 10 WTRTs in WR resulted in greater net returns than the same treatments in NR. In 1996, average net return across WTRTs in WR was greater than that from NR, and this was probably related more to weather pattern than to the system. The choice of using NR or WR in the ESPS depends on whether a MG IV cultivar (non-branching growth type, short stature, and early maturity suited to narrow rows) or a MG V cultivar (branching growth type, taller stature, and later maturity suited to wide rows) is desired. These results show that the cheapest weed management used for both NR and WR systems in nonirrigated ESPS plantings resulted in the greatest net returns, and only management of broadleaf weeds was required at this site which is representative of millions of dryland soybean hectares in the region. We suggest that annual grasses either emerge in these early plantings too late to be competitive, or they are not competitive in the dryland environments where late-season soil moisture is limited as typified by the conditions of this study. These conclusions should pertain to the large clay hectarage in the midsouthern USA where johnsongrass has been controlled.

ACKNOWLEDGMENTS

The authors appreciate the technical assistance provided by Lawrence Ginn, Ray Adams, and John Black; resources provided by Delta Research and Extension Center; and supplemental funding provided by the United Soybean Board and the Mississippi Soybean Promotion Board.

REFERENCES

Askew, S.D., J.E. Street, and D.R. Shaw. 1998. Herbicide programs for red rice (*Oryza sativa*) control in soybean (*Glycine max*). Weed Technol. 12:103–107.

Boquet, D.J. 1998. Yield and risk utilizing short-season soybean production in the mid-southern USA. Crop Sci. 38:1004–1011.

Boykin, D.L., R.R. Carle, C.D. Ranney, and R. Shanklin. 1995. Weather Data Summary for 1964–1993, Stoneville, Mississippi. Tech. Bull. 201. Mississippi Agricultural & Forestry Experiment Station, Mississippi State Univ., Mississippi State, MS.

Bowers, G.R. 1995. An early soybean production system for drought avoidance. J. Prod. Agric. 8:112–119.

Buhler, D.D., R.P. King, S.M. Swinton, J.L. Gunsolus, and F. Forcella. 1997. Field evaluation of a bioeconomic model for weed management in soybean (*Glycine max*). Weed Sci. 45:158–165.

Elmore, C.D., and L.G. Heatherly. 1988. Planting system and weed control effects on soybean grown on clay soil. Agron. J. 80:818–821.

Ginn, L.H., E.R. Adams, L.G. Heatherly, and R.A. Wesley. 1998a. A canopied sprayer for accurate application of herbicides. Agron. J. 90:109–112.

Ginn, L.H., L.G. Heatherly, E.R. Adams, and R.A. Wesley. 1998b. A sprayer for under-canopy application of herbicide sprays. J. Prod. Agric. 11:196–199.

Heatherly, L.G. 1999a. Early soybean production system (ESPS). p. 103–118. *In* L.G. Heatherly and H.F. Hodges (ed.). Soybean production in the mid-south. CRC Press, Boca Raton, FL.

Heatherly, L.G. 1999b. The stale seedbed planting system. p. 93–102. *In* L.G. Heatherly and H.F. Hodges (ed.). Soybean production in the mid-south. CRC Press, Boca Raton, FL.

Heatherly, L. G., and G. Bowers. 1998. Early soybean production system handbook. USB 6009-091998-11000. United Soybean Board, St. Louis, MO.

Heatherly, L.G., and S.R. Spurlock. 1999. Yield and economics of traditional and early soybean production system (ESPS) seedings in the midsouthern USA. Field Crops Res. 63:35–45.

Heatherly, L.G., C.D. Elmore, and S.R. Spurlock. 1994. Effect of irrigation and weed control treatment on yield and net return from soybean (*Glycine max*). Weed Technol. 8:69–76.

Heatherly, L.G., R.A. Wesley, C.D. Elmore, and S.R. Spurlock. 1993. Net returns from stale seedbed plantings of soybean (*Glycine max*) on clay soil. Weed Technol. 7:972–980.

Hooker, D.C., T.J. Vyn, and C.J. Swanton. 1997. Effectiveness of soil-applied herbicides with mechanical weed control for conservation tillage systems in soybean. Agron. J. 89:579–587.

Hydrick, D.E., and D.R. Shaw. 1995. Non-selective and selective herbicide combinations in stale seedbed (*Glycine max*). Weed Technol. 9:158–165.

Johnson, W.G., J.S. Dilbeck, M.S. DeFelice, and J.A. Kendig. 1998. Weed control with reduced rates of chlorimuron plus metribuzin and imazethapyr in no-till narrow-row soybean (*Glycine max*). Weed Technol. 12:32–36.

Johnson, W.G., J.A. Kendig, R.E. Massey, M.S. DeFelice, and C.D. Becker. 1997. Weed control and economic returns with postemergence herbicides in narrow-row soybeans. Weed Technol. 11: 453–459.

Krausz, R.F., G. Kapusta, and J.L. Matthews. 1995. Evaluation of band vs. broadcast herbicide applications in corn and soybean. J. Prod. Agric. 9:380–384.

Mickelson, J.A., and K.A. Renner. 1997. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. J. Prod. Agric. 10:431–437.

Newsom, L.J., and D.R. Shaw. 1996. Cultivation enhances weed control in soybean (*Glycine max*) with AC 263,222. Weed Technol. 10:502–507.

Oliver, L.R., T.E. Klingaman, M. McClelland, and R.C. Bozsa. 1993. Herbicide systems in stale seedbed soybean (*Glycine max*) production. Weed Technol. 7:816–823.

Pettry, D.E., and R.E. Switzer. 1996. Sharkey soils in Mississippi. Bull. 1057. Mississippi Agricultural & Forestry Experiment Station, Mississippi State Univ., Mississippi State, MS.

Poston, D.H., E.C. Murdock, and J.E. Toler. 1992. Cost-efficient weed control in soybean (*Glycine max*) with cultivation and banded herbicide application. Weed Technol. 6:990–995.

SAS Institute. 1996. SAS system for mixed models. SAS Institute Inc., Cary, NC.

Spurlock, S.R., and D.H. Laughlin. 1992. Mississippi state budget generator user's guide version 3.0. Agric. Economics Tech. Publication No. 88. Mississippi State, MS.

Swanton, C.J., T.J. Vyn, K. Chandler, and A. Shrestha. 1998. Weed management strategies for no-till soybean (*Glycine max*) grown on clay soils. Weed Technol. 12:660–669.

Williams, B., 1999. Economics of soybean production in Mississippi. p. 1–17. *In* L.G. Heatherly and H.F. Hodges (ed.). Soybean Production in the Mid-south. CRC Press, Boca Raton, FL.

Yelverton, F.H., and H.D. Coble. 1991. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (*Glycine max*). Weed Technol. 5:169–174.